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Translated From
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BONDING OF FOAM PLASTICS BY MEANS OF HIGH-FREQUENCY HEATING

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Foam plastics PS-1, PS-4, PVKh and others are manufactured by pressure methods. For mass production this method requires complex pressure molds, powerful presses, and cumbersome equipment. Besides, to obtain products of large dimensions (larger than 1.5 - 2 m) with precise sizes is very difficult due to warping and swelling of foam plastics. It is considerably more simple to manufacture products of comparatively small sizes and then bond them together. However, for strengthening the bond it is necessary to maintain the material under pressure for a period of 20 - 24 hours after bonding.

Heating speeds up the bonding. However, during bonding of foam plastics external heat cannot be used, because at a temperature of 60 - 70° C, the material deforms.

For correction of these shortcomings, TSNII (All Union Central Scientific Research Institute) of structural construction of the AS and A (Academy of Structures and Architecture) USSR, studied the possibility* of connecting (bonding) foam plastics by means of internal heating in a high-frequency field that speeds up the process and gives a firm connection.

Bonding is performed as follows. On the surface of one of the parts

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* A. F., Ipatov, N. G., Kyunina, P. V. Godilo; took part in the experimental phase. E. P. Parini made studies of dielectrical features.

to be bonded, a thin layer of adhesive (or water) is spread; the parts are then compressed and placed in a high-frequency electrical field. The damp inner layer is quickly heated to 100 - 130° C, and the joined layers of foam plastic fuse and bond.

During the experimental processes the characteristics of the behavior of materials during heating were studied, heating conditions and regimes were found, and dielectric properties (ε and tgδ) of the foam plastic and the zones of bonded seams before and after bonding were measured.

Foam plastics from the press method production were used in the tests: polystyrene PS-1 and PS-4, and also polyvinyl-chloride PVKh-1.

The following adhesives were used: urea-formaldehyde M-70, K-17, MF, urea-melamine-formaldehyde MMF and phenol-formaldehyde KB-3.

The adhesive was applied unilaterally in the amount of 150 - 200 g/cm^2.

Dielectric properties were measured with type KB-1 Q-meter. Specimens 140 x 140 mm for measuring the zone of the bonded seam, and specimens 70 x 70 for measuring the zone of the foam plastic were cut out, and several layers were placed between the electrodes of a plane parallel capacitor.

For calculating the capacities of the edge and of the air portion (not filled with foam plastic) of the capacitor, its capacity was preliminarily measured. For determining the parameters of an adhered seam two measurements were taken — one with and one without the adhesive. The parameters of the zone of an adhered seam of the specimens of foam plastic PS-1 were determined by calculating the zone thickness as 0.05

cm, and for foam plastic PS-4, as 0.2 cm.

Before heating, an adhesive layer* was applied on the surface of one specimen, after which the specimens were squeezed by a pressure force of 0.5 to 1.5 kg/cm^2, which was measured by a screw indicator.

High frequency energy from a tube generator of type LGE-3B was fed by a coaxial cable to the electrodes, between which a moist heating layer was located.

Measurements of deformations of the specimens and determination of the strengths of the bonds were made at various heating regimes of foam plastics. A cold bonding method, during which the specimens were bonded by adhesive KB-3, was used in order to obtain comparative data.

During introduction of an adhesive, dielectric indices of the zone of the adhered seam k_z considerably changed in comparison with dielectric exponents of the foam plastic k_p. (Tab. I).

As may be seen from Table 1, the ratio of the loss factor of the adhered seam zone k_z to k_p of the foam plastic comprises 3880. This creates a favorable condition for selective heating of the zones of adhered seams. During heating the loss factor considerably changes (from 3.95 to 0.72) only in the first 5 seconds.

By measuring dielectric properties it was established, that the adhesives applied on the surfaces to be adhered are not absorbed by the material, in connection with which the loss factor of the adhesive seam practically does not change even after a 15 minute closed exposure (Fig. 1).

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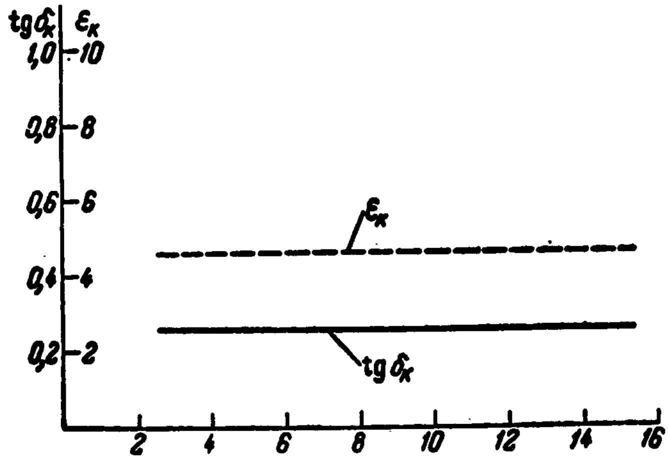
* In some cases water was used instead of an adhesive.

Dielectric exponents of foam plastic PS-4 and the zones of its adhered seams in the heating process.

(Adhesive M = 70, f = 10 Mcps; thickness of adhesive zone ΔK = 0.2 m)

Table I

Material	Condition of measurements	ε	$tg\delta$	$k=\varepsilon \times tg\delta$	$\frac{k_z}{k_p}$
Foam plastic PS-4	Before heating	1.05	0.001	0.00105	—
Adhered seams zone	Before heating	6.8	0.58	3.95	3880
	After heating for periods of				
	5 sec	4.8	0.15	0.72	685
	10 sec	4.7	0.14	0.66	630
	20 sec	4.8	0.12	0.57	542
	30 sec	5.0	0.08	0.4	380
	40 sec	5.0	0.05	0.25	238
	60 sec	4.8	0.05	0.24	229



Time in Minutes

Figure 1. Dependence of ε and $tg\delta$ of the adhesive seam zones on the duration of a closed exposure. Foam plastic PS-4, Adhesive M-70, Δk = 0.2 cm, f = 5 Mcps.

This creates very favorable conditions for intense selective heating of the adhesive-seam zones. In all tests performed to determine the behavior of foam plastic specimens in a HF field, a very rapid heating of the material in the adhesive seam zones was observed. 1 - 2 seconds after the heat (E = 0.7 - 0.8 kv/cm; f = 10 Mcps), was switched on, the adhesive began to boil; and after 7 - 9 sec. the boiling ceased. In certain instances the material deformed during heating, and swelling was observed in the zone of the adhesive layers; the extent of deformation depended on the brand of foam plastic, the regimes of bonding, and on the pressure applied. During heating of foam plastics PS-1 and PS-4 for 7 - 9 sec., the period required for bonding, there was practically no deformation (Fig. 2).

Figure 2. Bonded specimens of PS-4 foam plastic after heating for 7 - 9 sec.

However by further heating to 10 - 12 sec., a comparatively small increase in the dimensions of the specimen was observed.

The behavior of foam plastic PVKh, especially PSB, was completely different. After the foam plastic PVKh was heated for over 5 sec, its dimensions changed considerably; the material in the adhesive seam zone fused strongly, swelled and expanded by approximately $^2/_3$ in breadth. Heating for 3 - 5 sec., did not cause any significant deformations of the material except in rare instances.

Specimens of foam plastic PSB swelled strongly after 2 - 3 sec. from the time the heat was switched on (Fig. 3). Boiling of the adhesive was hardly noticed. Due to strong deformation of the specimens further tests with this material were terminated.

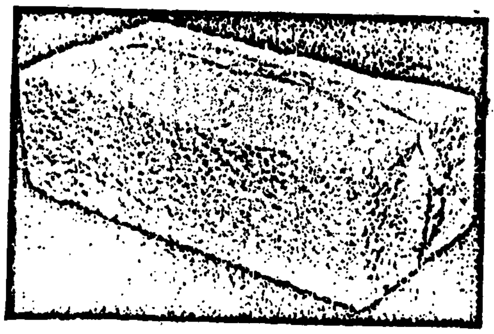


Figure 3. Swelling of foam plastic PSB after 3 sec. of heating.

It was established that the bonding process depends on the type of adhesive used. Adhesives of a carbamide group behave practically the same during the heating process. Only when the phenol group of adhesives (KB-3) is used are frequent burns observed. This especially pertains to specimens of foam plastic PS-4; even the presence of an air gap of 6 mm does not prevent burns. The only exception is foam plastic PVKh. By decreasing the heat intensity (E = 0.47 - 0.5 kV/cm; f = 10 Mcps), the boiling of the adhesive starts only after 17 - 18 sec. and terminates after 27 - 30 sec.

Table II

Bonding strength of foam plastic specimens by high-frequency heating and by a cold method.

Brand of foam-plastic	Period of heating sec.	Stability, kp/cm²						
		cold method of Bonding	Bonding by means of high frequency heating					
			M-70	K-17	MF	MMF	KB-3	water
PS-4	3		3–4 / 3,2	2–4 / 3	3–3 / 3,4	2–3 / 2,8	Burns	does not bond
	5	2–3 / 2,6	2–4 / 3	2–4 / 3	3–4 / 3,5	3–4 / 3,5		
	10		2–4 / 3	2–4 / 3	3–6 / 3,7	2–4 / 3,3		
PS-1	3		11–16 / 13,6	9–15 / 11,4	8–11 / 9,9	8–24 / 14,6	11–25 / 15,2	"
	5	9–11 / 10	11–18 / 14,7	10–17 / 12,9	8–16 / 10,9	17–25 / 15,5	11–22 / 15,6	
	10		8–18 / 12,3	8–12 / 10,5	8–19 / 13	11–16 / 13	8–19 / 12	
PVkh	3		8–12 / 9,5	5–9 / 7	6–9 / 7,1	8–11 / 9,9	7–12 / 9,1	4–7 / 5,6
	5	7–13 / 11,5	5–11 / 7	5–8 / 7	6–9 / 7,4	6–10 / 7,6	6–9 / 7,9	5–8 / 6,6
	10		Strong fusing of the material					

Remarks.

1. Exposure time was 24 hours at a temperature of 18 - 20° C during bonding by a cold method. Adhesive KB-3.
2. High-frequency heating was performed with a gradient of stress E = 0.75 kv; f = 10 Mcps, pressure 0.5 kp/cm2.
3. The lowest and the highest values are indicated in the numerator; the average values, in the denominator. In the majority of cases some destruction occurs on the boundary of an adhesive seam of the material; it is impossible to determine the destruction percentage-wise.

With an increase in the duration of heating and of the dimensions of the specimens the work regime of the generator changes somewhat; however, an additional adjustment is not required. As may be seen in Table II, during bonding of foam plastic PS-1 and PS-4 a sufficiently strong bond is attained after a heating period of only 3 - 5 seconds, as compared with the strength of bonding by a cold method. A further heating of the specimens will not essentially increase their strength. The bonding strength of specimens of foam plastic PVKh achieved by high-frequency heating is somewhat lower than that achieved by a cold method of bonding, which is due to the influence of deformation of the material. The bonding strength of foam plastics by adhesives of carbomide groups does not depend practically upon the brand of the adhesive. By using KB-3, a good bond is achieved only for PS-1 in spite of frequent burns. Bondings with water give comparatively good results only for foam plastics PVKh.

As indicated above, the material is exposed to deformation during high frequency heating of foam plastics. It was established, that in a majority of cases, during the first 3 - 5 seconds of heating, an insignificant decrease in the dimensions of the specimens occurs perpendicular to the plane of the adhesive seam. With further heating the dimensions of the specimen start to increase. Such changes in dimensions of the specimens depend on the brand of foam plastic. Actually, however, during the time of bonding (7 - 9 sec.) total changes in dimensions of the specimens are within permissable limits.

Foam plastics PVKh deform somewhat differently during heating.

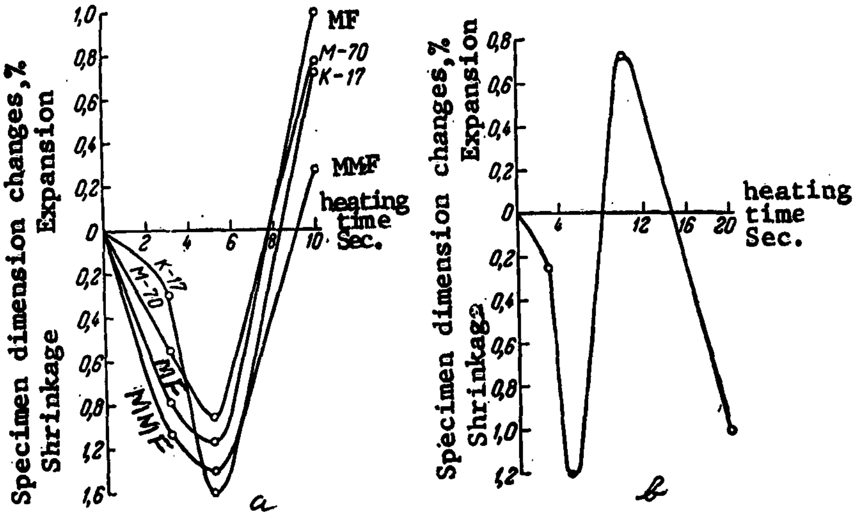


Figure 4. Deformation of foam plastic PS-4 during bonding
a —heating 10 sec. *b*—heating 20 sec. (adhesive K-17).

An expansion of the specimen occurs after only 3 seconds of heating, and this happens very rapidly; also, after 10 seconds the material swells and fuses strongly. Foam plastic PS-1 virtually does not deform.

The change in dimensions depends also on the intensity of the pressure applied during heating (Fig. 5).

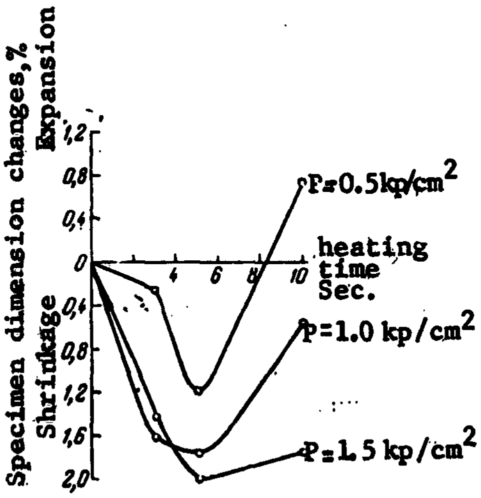


Figure 5. Deformation of foam plastic PS-4 dependent on the value of the applied pressure.

Thus, deformation of foam plastic specimens during high frequency heating depends upon the brand of foam plastic, the regimes of bonding and the pressure applied. The nature of the change in dimensions of foam plastics of all brands is basically the same and does not depend on the type of adhesive.

Findings

It was established that foam plastics of certain brands (PS-4, PS-1) may be bonded by carbamide adhesives by means of high-frequency heating in a very short period of time of 5 - 7 seconds, instead of 20 to 24 hours by the usual means of bonding. Deformation of the material occurring during this heating are small. Strengths of bonding are analogous to the ones, attained by a cold bonding method.

For bonding foam plastics PVKh, the indicated method is applicable only for a brief period of heating (3 - 5 seconds) since a prolonged heating causes a strong deformation of the material. This should be taken into consideration when heating regimes are selected for foam plastics produced by press methods.